aligned to correspond with the position of rack **9** in a vehicle start-up situation. Upon such alignment the solenoid actuated by-pass spindle **64** is shifted to its closed position. The control module then executes a health status check. All systems are automatically computer verified to be in proper working order. The control module **74** then reports that the system is ready to receive steering input from the vehicle. This typical start-up procedure is completed in a fraction of a second with suitable conventional computer software control systems applied in accordance with the foregoing parameters of the power steering system of the invention.

What is claimed is:

1. An electro-hydraulic power steering system comprising an elongated rack adapted to be connected at opposite ends to the steerable wheels of a motor vehicle, said rack having a series of teeth along a section of its length, a rotatable pinion in mesh with the rack teeth and adapted to be operably connected to a steering wheel of the vehicle by a shaft so as to receive vehicle operator steering input, said rack extending lengthwise within an elongated housing constructed to form an elongated power cylinder and having thereon spaced apart first and second circular interior portions of reduced diameter defining the axially opposite ends of said power cylinder and having a sealed engagement with the rack in order to close opposite ends of said power cylinder, a piston carried by said rack within said power cylinder having a sealed engagement with the interior of the cylinder and separating the cylinder into first and second power assist working chambers filled with hydraulic fluid, a first fluid line communicating with said first power chamber adjacent one end of said power cylinder, a second fluid line communicating with said second power chamber adjacent to the other, axially opposite end of said power cylinder, a hydraulic actuator cylinder sealed at opposite ends by first and second end caps, a linear drive screw extending lengthwise within said actuator cylinder and having its opposite ends rotatably received in said end caps for rotation in both directions about its central longitudinal axis and secured against axial displacement thereof, an actuator piston reciprocable within said actuator cylinder and separating said actuating cylinder into first and second hydraulic fluid filled actuating chambers, said actuator piston being secured against rotation in said actuating cylinder and said drive screw extending through and being threadedly engaged with said actuator piston such that rotation of said drive screw is operable to produce linear movement of said actuator piston in one direction or the other depending upon the direction of rotation of the drive screw, said drive screw extending through said second end cap and being operably rotationally driven connected to a servo motor carried by said second end cap, said first and second fluid lines respectively communicating with said first and second actuating chambers on opposite sides of said actuator piston such that the hydraulic fluid filling said actuating chambers is fed to and from said first and second power chambers on the opposite sides of said rack piston within said power cylinder by motion of said actuator piston under control of said motor and said drive screw, a fluid cross-over by-pass line connecting said first and second fluid lines, a solenoid valve connected in said cross-over line having a valve element normally held open by a valve spring but closed by energization of the valve solenoid such that when said valve is open fluid is merely displaced from one side of the rack piston to the other and thus between said power chambers in by-pass relation to said actuator chambers, first and second pressure sensors operably coupled respectively in said first and second fluid lines such that when the vehicle operator provides a steering input to said rack by means of said pinion, the resultant motion of said rack and consequent motion of said piston within said power cylinder creates a pressure differential in said rack power chambers which is sensed by said pressure sensors to generate a corresponding pressure differential signal, an electronic controller operably coupled to receive the pressure differential signal from said pressure sensors and operably coupled to provide a corresponding control signal to said bypass valve for controlling the same and to said motor so as to command rotation of said drive screw and consequent motion of said actuator piston in a direction to force hydraulic fluid from a system selected one of said actuator chambers into an associated one of said power cylinder chambers so as to minimize the fluid pressure differential existing between said two sensors, said electromotivally developed motion of said actuator piston and consequent hydraulically-developed fluid flow forces thereby providing steering assist power in said power cylinder to assist the vehicle operator in manually applying torque via said steering wheel to achieve the desired motion of said rack to thereby move the steerable vehicle wheel.

2. The system set forth in claim **1** including disabling means operable such that when the vehicle is operated at a relatively low speed the power steering system is effective, but at higher speeds, when power assist is not demanded, power assist is disabled, said disabling means comprising a vehicle speed sensor operable to input a signal to said electronic controller for causing said controller to de-energize said by-pass valve solenoid and open said by-pass valve and thereby disable the power assistance at such higher speeds.

3. The system set forth in claim **2** wherein said disabling means is also operable in an emergency situation, when the operator of the vehicle makes a sudden lane change, thereby manually generating via said pinion and said rack a momentary increase in fluid pressure in one of said power chambers of the power cylinder, such increase being operably sensed by one of said sensors, thereby sending a signal to said controller operable to energize said solenoid to close said by-pass valve and allow the power assist to return to normal operation.

4. The system set forth in claim **1** having position control means operable, when initially starting a vehicle, to determine the operating positions of said rack piston and said actuator piston relative to one another, including a rack position encoder and an associated sensor reader operable for reading the rack position and an actuator piston encoder and associated sensor reader for reading the position of the actuator piston, said encoders and sensors being operably coupled to said electronic controller such that when staring the vehicle said electronic controller receives a position reading signal from each of said encoder/sensors and the results are operably compared by said controller and, if necessary, said controller will control said by-pass valve and will activate said motor to rotate said lead screw in the appropriate direction to move said actuator piston into a position to correctly correspond with the position of said rack piston.

5. The system of claim **4** wherein said controller is adapted to be powered by the d.c. power system of the vehicle, said controller comprising a micro-controller in the form of an application specific integrated circuit that includes an integrated digital signal processor and appropriate analog-to-digital and digital-to-analog converters, and operable to respond for system control to the following external inputs to said controller:

1. vehicle ignition status;
2. pressure sensor inputs;
3. rack position encoder;
4. actuator piston position encoder; and
5. vehicle speed sensor.

6. The system of claim 5 wherein said controller is operable to respond to system internal inputs to the controller in the form of status bits wherein the system is operable to monitor its own health by comparing known real time output values to expected values found in look-up tables, said internal inputs comprising:

1. resistance to impedance measurements on rotor windings;
2. amperage required to achieve a particular torque value; and
3. rotor winding temperature.

7. The system set forth in claim 6 wherein said controller is operable to provide a digital output from the controller in the form of:

1. digital voltage and amperage values for operating said actuator motor, and wherein the sign of digital voltage value indicates polarity and thus rotation position,
2. system status bits made available to the user for component monitoring purposes, and

wherein such digital values received from the controller are converted to useable analog values by said analog-to-digital converter.

8. The system set forth in claim 7 wherein said system controller is programmed to be operable in a vehicle startup situation, such that when the vehicle ignition is turned on, said controller executes a startup procedure to de-energize said bypass valve solenoid, thereby opening said valve, and in response to signals from said position sensor-the results are compared and said controller then activates said motor to rotate said lead screw as needed to move said actuator piston relative to said rack piston such that the positions of said two pistons correspond, and upon alignment of said two pistons, said controller energizes said bypass valve solenoid to thereby close said valve so that power assist of said system is operative, whereupon said controller executes a health status check, and if all systems are verified and in proper working order, said controller is conditioned such that the system is ready to receive steering input with power assist, said starting procedure being completed in only a fraction of a second.

9. The system set forth in claim 8 wherein as a fail-safe feature of said system said controller is operable to de-energize said solenoid and thereby allow said valve biasing spring to open said bypass valve in the event of a system failure so that the vehicle operator will have complete control over the vehicle, but without power assist.

10. The system set forth in claim 1 further including additional sensors, namely a steering column absolute position encoder/sensor that is adapted to sense angular rotation of the vehicle steering wheel as inputted to the vehicle steering column, and a conventional steering column torque encoder/sensor;

and wherein said steering wheel absolute position encoder/sensor is operable to provide the following steering wheel information:

a. the angular displacement in degrees left or right from the center position, the center position being defined as the point where the vehicle steerable wheels are oriented straight ahead;
b. the rate at which the steering wheel is being turned by the vehicle operator measured in degrees per second;

and wherein said steering wheel position encoder/sensor information is analyzed and used for:

a. initialization and positioning of said actuator piston in the steering assist module at the time of vehicle start-up; and
b. all steering maneuvers such that said steering wheel position encoder/sensor information is thus used by operation of said system to calculate the required rpm of said electric motor for steering assists operations.

11. The system set forth in claim 10 wherein the system is programmed and operable such that the data obtained from said torque encoder/sensor is used in conjunction with data from said pressure transducers and integrated to determine and control the magnitude of the torque output of said motor to be applied to said actuator piston to thereby develop the hydraulic fluid pressure to assist vehicle steering operation, and wherein such data is also used to differentiate between vehicle operator input and road induced phenomena by provision of suitable software systems in said controller.

12. The system set forth in claim 11 wherein said system is constructed, arranged and operable such that said electronic controller is bi-directionally coupled by an exchange patch connection to a multiplexed vehicle network, wherein the signals from said pressure sensors, from said rack position encoder/sensor and from said actuator piston position encoder/sensor are initially inputted to said controller, and the output from said controller is operable to control both said motor and said solenoid valve, whereas the on/off input signal of the system, the vehicle speed data, the steering torque data from said torque encoder/sensor as well as the steering wheel position data from said steering column position encoder/sensor are inputted initially to said multiplexed vehicle network and wherein said system is operable to provide bi-directional exchange of system data over said multiplexed vehicle network via a patch link thereof with said controller, and wherein said multiplexed vehicle network is adapted to share with the conventional vehicle on-board ECU the power steering system status, pressure sensor data, rack position data and actuator sensor data, and wherein suitable software is provided in said system such that system performance is monitored, system diagnostics are analyzed and system performance is enhanceable by suitable changes in such software.

13. The system set forth in claim 1 wherein said electric/hydrostatic steering assist system components are constructed and arranged to integrate said power assist actuator cylinder, piston, and motor within a housing for said rack such that the system with integrated components can be shipped as one assembly in a charged state, filled with steering fluid, so as to eliminate fluid handling processes at the vehicle assembly plant.

14. The system set forth in claim 1 wherein the system components are separated into main sub-assemblies consisting of a power actuator piston, cylinder and motor module, a solenoid valve module, and a rack and pinion steering gear and power assist cylinder component module, whereby said power actuator module along with the fluid coupling lines 30 and 32 can be conveniently located remote from said rack and pinion power assist module as best suits the vehicle application installation, such modular flexibility of the system thereby reducing the vehicle packaging constraints.

15. A power steering apparatus comprising a hydraulic actuator having a pair of power assist cylinder chambers and operable to generate assisting power;

a hydraulic pump for supplying pressurized fluid via supply passageway means to said power assist chambers;

an electric motor for operating said hydraulic pump;

a control valve mechanism operable by a system controller for bypassing between said pair of power assist cylinder chambers of said hydraulic actuator the pressurized fluid supplied by said hydraulic pump through said supply passageway means;

detection means for detecting differential pressure between pressures in said pair of power assist cylinder chambers; and

motor control means responsive to the output of said detection means for controlling said electric motor to thereby cause it to drive said pump in accordance with the steering wheel position so as to return the differential pressure to a predetermined first value, said hydraulic pump comprising a double-acting ram actuator piston and cylinder unit having a pair of working chambers separated by said actuator piston and respectively communicating with said pair of power assist cylinder chambers.

16. The apparatus of claim **15** wherein said electric motor is a servo motor and is operable to bi-directionally rotatably drive a lead screw on which said piston is operably threadably received for travel therealong in response to screw rotation.

17. An electro-hydraulic power steering system comprising an elongated rack adapted to be connected at opposite ends to the steerable wheels of a motor vehicle, said rack having a series of teeth along a section of its length, a rotatable steering gear in mesh with the rack teeth and adapted to be operably connected to a steering wheel of the vehicle by a shaft so as to receive vehicle operator steering input, said rack extending lengthwise within an elongated housing constructed to form an elongated power assist cylinder, a piston carried by said rack and separating said power assist cylinder into first and second power assist working chambers filled with hydraulic fluid, a hydraulic actuator cylinder, a linear drive screw extending lengthwise within said actuator cylinder and journalled for bi-directional rotation and against axial displacement, an actuator piston non-rotatably but reciprocably mounted within said actuator cylinder and separating said actuating cylinder into first and second hydraulic fluid filled actuating chambers, said drive screw extending through and being threadedly engaged with said actuator piston such that bi-directional rotation of said drive screw is operable to produce corresponding bi-directional linear movement of said actuator piston, a servo motor operably coupled to said lead screw for controllably bi-directionally rotating the same, first and second fluid lines respectively communicating said first and second actuating chambers on opposite sides of said actuator piston and communicating respectively with said first and second power assist chambers such that the hydraulic fluid filling said actuating chambers is fed to and from said first and second power chambers on the opposite sides of said rack by linear motion of said actuator piston under control of said servo motor and said drive screw, a fluid cross-over by-pass line connecting said first and second fluid lines, a bypass valve connected in said cross-over line and operable such that when said valve is open fluid is merely displaced between said power chambers in by-pass relation to said actuator chambers, first and second pressure sensors operably coupled respectively in said first and second fluid lines such that when the vehicle operator provides a steering input to said rack the resultant motion of said rack and piston within said power cylinder creates a pressure differential between said rack power chambers which is sensed by said pressure sensors to thereby generate a corresponding pressure differential signal, an electronic controller operably input coupled to receive the pressure differential signal and operably output coupled to provide a corresponding control signal to said bypass valve for controlling the same and to said motor so as to command rotation of said drive screw and consequent motion of said actuator piston in a direction to force sufficient hydraulic fluid from one of said actuator chambers into an associated one of said power cylinder chambers so as to minimize the fluid pressure differential existing between said two sensors, said electro-motivally developed motion of said actuator piston and consequent hydraulically-developed fluid flow forces thereby providing steering assist power in said power cylinder to assist the vehicle operator in manually applying torque via said steering wheel to achieve the desired motion of said rack to thereby move the steerable vehicle wheel.

18. The system set forth in claim **17** including disabling means operable such that when the vehicle is operated at a relatively low speed the power steering system is effective, but at higher speeds, when power assist is not demanded, power assist is disabled, said disabling means comprising a vehicle speed sensor operable to input a signal to said electronic controller for causing said controller to open said by-pass valve and thereby disable the power assistance at such higher speeds.

19. The system set forth in claim **17** wherein said disabling means is also operable in an emergency situation, when the operator of the vehicle makes a sudden lane change, thereby manually generating via said steering gear and said rack a momentary increase in fluid pressure in one of said power chambers of the power cylinder, such increase being operably sensed by one of said sensors, thereby sending a signal to said controller operable to close said by-pass valve and allow the power assist to return to normal operation.

20. The system set forth in claim **17** having position control means operable, when initially starting a vehicle, to determine the operating positions of said rack piston and said actuator piston relative to one another, and being operably coupled to said electronic controller such that when starting the vehicle, if necessary, said controller will control said by-pass valve and will activate said motor to rotate said lead screw in the appropriate direction to move said actuator piston into a position to correctly correspond with the position of said rack piston.

21. The system of claim **20** wherein said controller comprises a micro-controller operable to respond for system control to the following external inputs to said controller:

1. vehicle ignition status;
2. pressure sensor inputs;
3. rack position encoder;
4. actuator piston position encoder; and
5. vehicle speed sensor.

22. The system of claim **21** wherein said controller is operable to respond to system internal inputs to the controller in the form of status bits such that the system is operable to monitor its own health by comparing known real time output values to expected values found in look-up tables, said internal inputs comprising one or more of the following:

1. resistance to impedance measurements on rotor windings;
2. amperage required to achieve a particular torque value; and
3. rotor winding temperature.

23. The system set forth in claim **22** wherein said controller is operable to provide a digital output from the controller in the form of digital voltage and amperage values for operating said actuator motor, and wherein the sign of digital voltage value indicates polarity and thus rotation position.

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